DONALDSON (H. H.)

THE EXTENT OF THE VISUAL CORTEX IN MAN, AS DEDUCED FROM THE STUDY OF LAURA BRIDGMAN'S BRAIN.

HENRY H. DONALDSON, Ph. D.,

ASSISTANT PROFESSOR OF NEUROLOGY AT CLARK UNIVERSITY, WORCESTER, MASS.

Reprinted from The American Journal of Psychology, Vol. IV, No. 4, August, 1892.

THE EXTENT OF THE VISUAL AREA OF THE CORTEX IN MAN, AS DEDUCED FROM THE STUDY OF LAURA BRIDGMAN'S BRAIN.

HENRY H. DONALDSON, PH. D.,
Assistant Professor of Neurology in Clark University, Worcester, Mass.

Some peculiarities of the cerebral cortex, in the case of Laura Bridgman, have already been described in this JOURNAL [1, 2].

It was there pointed out that the three localities examined within the occipital lobe had the cortex thinner in the right hemisphere. The optic nerve and tract belonging to the left eye were the thinner, and in the right cuneus, the gyri were irregular. These facts all pointed to a greater disturbance affecting the right occipital lobe. Since in the left eye vision was completely lost at the age of two years, while it persisted up to the eighth year in the right, the thinness of the cortex on the right side was explained by the earlier loss of vision in the left eye, a lesion which was assumed to have arrested its development. Since the completion of the papers mentioned above, a further consideration of the case suggested that this brain might be used to determine the extent of the visual area in man. In following out this suggestion it has been assumed: (1) That the thinning of the cortex was due to an arrest of development; (2) that this thinning would extend over the entire visual area; (3) that, in the regions compared, the disturbance in vision was the principal influence acting to arrest unequally the growth of the cortex;

(4) that the cortex would be most thinned upon the side of the brain opposite to the eye and nerve most affected; (5) that the visual area in the normal brain gradually merges into the surrounding areas, and that hence the cortex on the outer limits of this area would, in this case, be but slightly different on the two sides.

The observations on which my conclusions are based were made in the following manner:

On a model of the brain, a boundary line was marked off as follows: Beginning at the mantle-edge on the dorsal surface the boundary passed laterad from the mesal end of the sulcus lying next caudad to the superior retrocentral sulcus, to the dorsal end of the ascending ramus of the first temporal sulcus, following this ventrad to its junction with the first temporal sulcus, and thence took the shortest path over the lateral and ventral surfaces, to the most cephalic end of the calcarine fissure, and there passed dorsad to join the mantle-edge at the point of departure. There was thus cut off a pyramidal portion of the hemisphere, with the plane of its base determined by this boundary, and having the occipital pole for its apex.

For the purpose of comparison, this surface was first divided into six areas, and ultimately, by subdivision, into ten areas. The following is a description of the areas.

I. The superior-parietal area. Bounded mesad by the mantle-edge, laterad by the interparietal sulcus, cephalad by the sulcus next caudad to the superior retrocentral sulcus, caudad by the anterior occipital sulcus.

I. was subdivided into a cephalic portion, I. (a), lying cephalad to the cephalic stipe of the interparietal sulcus, and a caudal portion, I. (b), lying caudad to the same.

II. The area of the angular gyrus. Bounded mesad by the interparietal sulcus, laterad by an arbitrary line uniting the junction of the first temporal and its ascending ramus to the transverse occipital sulcus, cephalad by the ascending ramus of the first temporal sulcus, and caudad by the anterior occipital sulcus.

II. was subdivided into a cephalic portion, II. (a), lying cephalad to the ascending ramus of the second temporal sulcus and a caudal portion, II. (b), lying caudad to the same.

III. Area of the cuneus. Bounded dorso-cephalad by the parieto-occipital sulcus, ventrad by the calcarine fissure, and caudad by the mantle-edge.

IV. The area of the occipital pole. Bounded mesad by the mantle-edge which separates it from the cuneus, laterad and cephalad by the anterior occipital sulcus, caudad by the

lateral occipital sulcus, and an arbitrary line joining the mesal end of the latter with the calcarine fissure.

IV. was subdivided into a lateral portion, IV. (a), lying laterad to a secondary sulcus which runs through the middle of this area, parallel to the mantle-edge, and a mesal portion, IV. (b), lying mesad to the same.

V. The praecuneal area. This includes that part of the praecuneus which lies cephalad to the parieto-occipital sulcus, and caudad to the boundary line.

VI. The ventral area. Bounded mesad by the calcarine fissure, laterad and caudad by the lateral occipital sulcus and its arbitrary continuation to the junction of the first temporal sulcus with its ascending ramus, cephalad by the base line.

VI. was subdivided into a mesal portion, VI. (a), lying between the calcarine fissure and the fourth temporal sulcus, including, however, only the dorsal two-thirds of the gyrus lingualis, and a lateral portion, VI. (b), lying laterad to VI. (a).

The brain itself was now compared with the model. The portion corresponding to each one of the ten areas just enumerated was cut into a number of blocks, and the position of each block was carefully marked on the model. The block was then mounted and the thickness of the cortex determined. There were sixty-two such blocks for each hemisphere.

The thickness of the cortex was determined in the following manner: The block was imbeded in celloidin and cut into sections about .05 mm. thick, stained with van Gieson's Picro-Fuchsin and mounted in the usual way.

By this stain the gray matter was colored a much deeper red than the white and thus well differentiated from it. The thickness of the cortical layer was measured with an eye-piece micrometer, each division of which had the value of .067 mm.

The following is the detail of the method of measurement: By means of a camera lucida each specimen was drawn on a card, being enlarged about six diameters. The actual length of the cortex in each specimen was next obtained by direct measurement. The thickness of the cortex was measured at the bottoms and sides of the sulci and at the summits of the gyri. Whenever any of these localities was sufficiently extended, more than one measurement was taken. In general the measurements of the thickness of the cortex were made at intervals of 5 mm.

Each measurement was then recorded at the corresponding point on the drawing of the specimen, and by this means any observation could be easily verified.

The above was all done by my assistant who was not informed of the purpose of the investigation.

The next step was to cover all the labels, both on the specimens and the drawings. The drawings were then shuffled and the specimens arranged in the final order in which the drawings stood. In this way the specimens from the right and left sides were mixed together and all order among them destroyed. All the measurements were then repeated by myself. The figures thus obtained were final and have not been altered.

As a result there was obtained for each section a length of cortex and a certain number of measurements giving the thickness of the cortex at about equal intervals of 5 mm. The average of the measurement for thickness multiplied into the length represented the area of the cross-section of the cortex in the given block. In order, however, to compare these areas with one another, it was necessary that the length of cortex should be the same on both sides. As this was rarely, if ever actually the case, the adjustment was made by always choosing as a norm the length of that side where the cortex was shortest. Iu comparing symmetrical points the difference in the area is thus rendered dependent upon the average thickness of the cortex alone.

In making up the tables from these observations it has to be kept in mind that if from one block in a certain area we have five or ten times the length of cortex that is obtained from its neighbor, that then the average derived from the measurements of this longer cortex applies to five or ten times as much of the region from which it is taken and hence should enter into the sum from which the average is derived five or ten times to its neighbor's once. In making the tables, therefore, the average thickness of the cortex for each block is multiplied by the length of cortex to which it applies. The areas thus obtained are added together and the sum divided by the number representing the sum of the several lengths of cortex. The quotient represents the average thickness of the cortex for the area in question, the thickness as determined for each block having thus been allowed its proportionate weight. Since the length of the cortex was very different in the different blocks the length in that block which had the shortest cortex was taken as a standard. The minimal length was just 5 mm. This length of 5 was taken as a unit, and all the other lengths have been written in the tables as multiples of this unit. In other words those numbers represent the true length of the cortex divided by 5. Since the reduced lengths enter as factors into the columns in which the areas are given, the figures there also represent

the true areas divided by 5. With this explanation we present the first table.

TABLE I.

To show the average thickness of the cortex in the several subdivisions, with the absolute difference between the two sides and thickness of right side in percent.

AREA. Name.	No.	Number of Blocks.	Length of Cortex divided by 5.	Area of Cortex in section, divided by 5. Left.	Right.	Average thickness in mm. Left.	R'h't	Left side standard. Absolute difference in mm.	Percentage thickness of the right side.	
Superior parietal.	I. a.	2	9.1	24.68	24.49	2.71	2.69	+.02	99.2	excluded.
Superior parietal.	I. b.	3	12.5	37.27	34.32	2.98	2.74	+.24	91.9	
Angular gyrus.	II. a.	5	20.5	58.09	56.97	2.83	2.78	+.05	98.2	
Angular gyrus.	II. b.	6	20.2	61.15	53.30	3.02	2.63	+.39	87.0	
Cuneus.	III.	11	38.7	82.69	79.13	2.13	2.04	+.09	95.7	
Occipital pole.	IV. a.	6	19.1	42.79	41.83	2 24	2.19	+.05	97.7	
Occipital pole.	IV. b.	3	14.8	32.76	31.93	2.21	2.15	+.06	97.2	
Praecuneus.	V.	4	19.6	53.56	58.97	2.73	3.00	—.27	109.8	excluded.
Meso-Ventral.	VI. a.	6	16.4	37.50	33.41	2.28	2.03	+.25	89.0	
Ventral.	VI. b.	17	60.1	140.82	148.37	2.34	2.46	—.12	105.1	excluded.

EXPLANATION OF TABLE I.

In this table are entered the numbers for the ten subdivisions. The numbers for the larger areas, e. g. I., etc., are not entered because in the presence of the subdivisions they are superfluous. They can, moreover, be obtained in any case by summing the numbers given for the component subdivisions.

Taking the columns of the table from left to right we have the following data:

(1) Name of area, (2) numerical designation of the subdivision, (3) the number of blocks cut from the subdivision, (4) the total length of the cortex in said blocks, divided by 5, as previously explained. This length has been adjusted so

that it is equal on both sides of the brain. The product of this last number into the number representing the average thickness of the cortex in this subdivision, first for the (5) left, then for the (6) right side. The number in millimeters, representing the average thickness of the cortex in the given subdivision, first for the (7) left, then for the (8) right side. The larger number of each pair in these two columns is printed in heavy faced type. (9) The absolute difference in millimeters between the pairs of figures in the last two columns, showing by how much the number for the left side exceeds that for the right. (10) The thickness of the right side expressed as a percentage. The thickness of the left side being taken as a standard i. e., equal to 100%. (11) Finally, "excluded" is put after each subdivision which can not be considered as part of the visual area.

The numbers for each subdivision as entered in Table I. have been derived from detail tables, giving the length of cortex and average thickness of the same for each block belonging to the subdivision. These detail tables would be worth publishing only in case they were accompanied by figures showing exactly the point at which each section was taken. At present that is not practicable, hence they are not given.

An examination of Table I. shows that in two subdivisions the cortex on the right side is thicker than on the left. Since we are determining the extent of only that cortex on the right side which is thinner, these two cases, V. and VI. (b), are to be at once excluded. In the remaining eight cases the thickness of the right side is from 99.2% to 87.0% of that of the left. The next question, therefore, is what difference may be considered significant for our purpose.

To this end we must determine first, what variations occur in the thickness of the two sides of normal brains.

I have determined the relative thickness of the occipital cortex in the brains of six males and three females, sampling each hemisphere at three points ([2, p. 62.]).

Conti([3]) has determined the same for seven males and four females. The figures apply to his post-rolandic region, namely all that which lies behind a vertical plain passing through the mesal end of the rolandic fissure.

Franceschi's([4]) observations were made on ten male and ten female brains and appear to apply to the occipital lobe of Ecker.

In general, then, the figures obtained by Conti and Franceschi are comparable with those which I have obtained from these last measurements of the Bridgman brain. The averages from the controls measured by myself are taken from

three localities only, and may, therefore, be expected to show greater variations than the figures of the Italian observers. The following, Table II., shows the thickness of the cortex in the left and right occipital lobes of the normal brain, giving the thickness of the right side as a percentage of that for the left.

TABLE II.

Authority.	Date	Locality examined.	Males. No. of Brains.	Males. Average thickness of Cortex in mm. Left.	Males. Average thickness of Cortex in mm. Right.	Males. Percentage thickness of right side.	Females. No. of Brains.	Females. Average thickness of Cortex in mm. Left.	Females. Average thickness of Cortex in mm. Right.	Females. Percentage thickness of right side.
Conti.	1884	Post Relandic Region.	7	2.08	2.06	99.0	4	2.03	2.03	100.0
Franceschi.	1886	Occipital Lobe.	10	2.28	2.29	100.4	10	2.16	2.14	99.0
Donaldson.	1891	Three points in Occipital Lobe.	6	2.65	2.62	98.8	3	2.48	2.54	102.4
						Average, 99.5				Average, 99.8

Table II. shows the greatest difference between the right and left sides in the case of the six normal males examined by myself, the right side being the thinner, 98.8% of the left. In the females the right side is less thin, averaging for the seventeen cases 99.8%, while for the twenty-three males it is 99.5%.

Taking the greatest difference found, 98.8%, and applying it to Table I. we exclude area I. (a), since there the right side differs from the left less than in the case of the normal males just cited.

The other differences shown in Table I. we may now regard as significant and employ them for plotting the visual area. See Plate I.

According to these figures the outline of the visual area is the following: Commencing where the cephalic stipe of the interparietal sulcus cuts the mantle-edge and passing laterocephalad along the latter to its junction with the inferior retrocentral sulcus, the boundary then takes the shortest line

to the ascending ramus of the first temporal sulcus, following this to its union with the sulcus, from here the shortest line to the lateral occipital sulcus from the mesal end of which an arbitrary line turns toward the fourth temporal sulcus, running parallel to this sulcus it cuts the gyrus lingualis so as to leave the ventral third of the latter in connection with the fourth temporal sulcus and continues to a point just ventrad of the cephalic end of the calcarine fissure, which it joins by an arbitrary line running dorsad, it then passes caudad along the calcarine fissure to the junction of the same with the parieto-occipital sulcus, and finally along this sulcus to the mantle-edge, then cephalad along the latter to the point of departure.

Such are the limits of visual area, as determined by this method, in the right hemisphere of the Bridgman brain.

All previous direct determinations of this area in man have been by the method of limited lesions, and I find that my outline follows so closely that given by Gowers([5]) in his diagram and obtained by the latter method, that I venture to think that the two methods lead to almost identical results and hence mutually support one another.

The visual area here outlined can, however, be examined in detail with advantage. The areas of the cuneus and that of the occipital pole [III., IV. (a) and IV. (b)] show the cortex on the right side only slightly thinner than on the left. The areas immediately around those just mentioned, viz., I. (b), II. (b) and VI. (a), show the greatest thinning on the right side. Beyond this second series we have but one other area, II. (a), in which the difference is again small.

The theoretical explanation for this relation of things is the following: The cuneus and the occipital pole form the more fundamental portion of the visual area, hence would be earlier developed and more resistant to disturbing influences. If such were the case the differential effect of the lesion would be less evident in this region because the growth was more nearly complete at the date of the injury. Moreover, both eyes are represented on each side in the areas of the cuneus and occipital pole, and hence the loss of sight in the left eye would have produced some arrest on the left side, though we should expect the arrest to be decidedly less than on the right. So much by way of explaining why the regions of the cuneus and occipital pole do not show greater differences in the two sides.

To explain why the surrounding region does show greater differences, I assume, first, that this region reaches complete development later, and would, therefore, be more affected under these conditions. Where the greatest difference occurs,

namely, in the caudal portion of the angular gyrus, II. (b). We have a region which is held by some authors to be in connection with the opposite eye mainly, and hence we have here two conditions which would induce the greatest difference in growth between the two sides. In the outermost area, II. (a), I look upon the visual representations as decreasing, hence the loss of vision would produce a less evident arrest here.

It is hardly desirable to further dwell on these explanations, since, in part at least, they can be tested, and it can thus be determined whether they are valuable.

In this connection there is one remaining observation to be noted. The mounted specimens of the cortex all show to the naked eye a clear stratification due to a light line. If the specimens are sorted according to the distinctness of the light line, disregarding the labels, and we put by themselves those in which the line is clear and sharp, it is found that we have all the samples of the cortex from the cuneus, the occipital pole, and also from the affected part of the gyrus lingualis.

It thus happens that the line of Baillarger or of Gennari, as it has been rechristened by Obersteiner, is co-extensive in this brain with portions of the visual area, which I have called fundamental, but also runs over to the gyrus lingualis, which can not be included in that part for the reasons above given. So evident a structural peculiarity must have some physiological significance, but this case as it stands, does not show what that is.

We conclude then that in this single brain we have the entire visual area marked out. This area includes the cuneus and angular gyrus, but does not pass on to the ventral surface. The thinning of the cortex is not the same throughout the visual area, but is small in the cuneus and occipital pole, large in the areas immediately surrounding it, and, finally, small again in the most outlying portions. The explanation which I have offered for this, is the stage of development in which the various portions of the cortex were found at the time vision was lost, and the degree to which each eye is represented in several portions of both areas. Finally, Gennari's line almost coincides with the fundamental portions of the areas, but oversteps it so far as to take in the dorsal portions of the gyrus lingualis, and thus, at present, cannot be explained as a peculiar character of the fundamental portion.

The idea involved in this investigation is not novel. The observations of Huguenin(6), Burckhardt(7), Mickle(8) and Mills(9) were based upon it, but this, I think, is the first time that advantage has been taken of an opportunity to apply it in detail.

To myself the point of most interest is that, if these conclusions are warranted, we have now, through the early destruction of sense-organs and the subsequent examination of the cortex, a means of experimentally determining in animals the limits of the several sensory areas. For the feasibility of this plan, the experiments of v. Gudden and his school already offer some indirect support.

Explanation of Plate I.

This plate has been made in the following way: On the right side the caudal portion of the right hemisphere is represented in some detail. There are three views: Fig. 1, lateral; Fig. 2, caudal; Fig. 3, mesal. The reversed outline of this same portion is represented on the left side of the plate. The boundary of the portion taken is marked by a heavy line. On the left side the limits of the subdivisions are all marked by broken lines, and within each subdivision is given its numerical designation and the average thickness of the cortex, in millimeters. These are repeated on the right side, but the broken lines are omitted. As will be seen, in certain cases, some of these data are omitted. No ventral view is given because the cortex there is excluded. The excluded portions, so far as shown, are left white, but on the right side the less affected subdivisions are hatched with a single line, while the more affected are so indicated by a doubly hatched line. The hatched portion on the right side, therefore, represents the visual area as determined.

Bibliography.

Reference Number.	Date.	Title.
1.	1890.	Donaldson, H. H. Anatomical observations on the brain and several sense-organs of the blind deaf-mute, Laura Dewey Bridgman. *American Journal of Psychology*, Vol. III, No. 3.
2.	1891.	Ibid. *American Journal of Psychology*, Vol. IV, No. 2.
3.	1884.	Conti, A. Dello spessore, della corteccia cerebrale nell' uomo. *Torino. Giornale della R. Academ. di Medicina.* Torino. Fasc. 11–12 Nov., Dec., 1884. (Full tables.
4.	1886.	Franceschi. Sulla varia grossezza della sostanza grigia degli emisferi cerebrale e dei centri psico-motori dell' uomo. Bologna. *Bull. d sc. Med. di Bologna*, 1886. 6s. XVIII, pp. 153. (Tables.)
5.	1888.	Gowers, W. R. A manual of diseases of the nervous system. Vol. II. London, 1888. Vide p. 19.

PLATE I.

Showing three aspects of the occipital lobe.

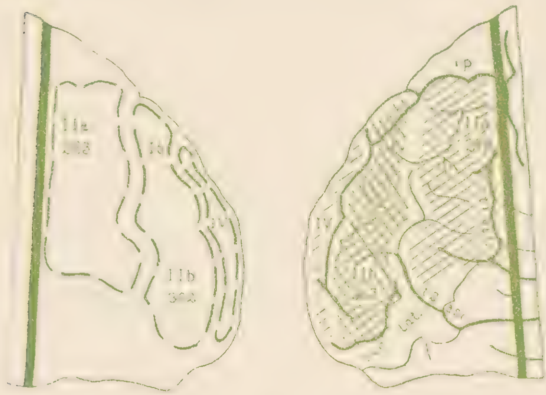

FIG. 1. Lateral aspect.

FIG. 2. Caudal aspect.

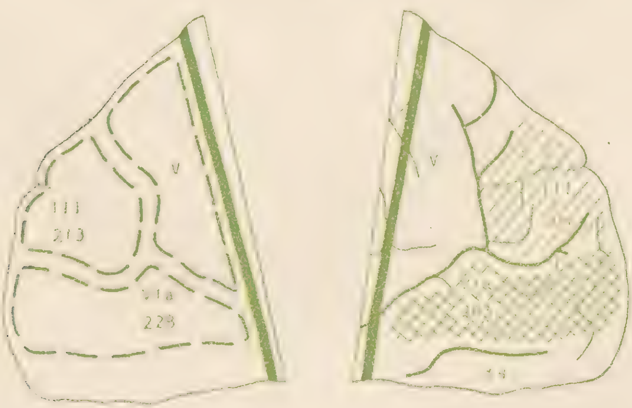

FIG. 3. Mesal aspect.

6. 1878. HUGUENIN. Ein Beitrag zur Physiologie der Grosshirnrinde. *Correspondenzblatt f. Schweizer Aerzte.* 1878. Nr. 22.

7. 1879. BURCKHARDT. Atrophie des Gyrus Angularis nach Verlust eines Auges. Bericht pro 1879 über die Berner Canton Anstalt, Waldau. (Abstract in *Centralblatt f. Nervenhielkunde, etc.* 1880, p. 361.)

8. 1892. MICKLE, W. J. Localization of the visual centres of the cerebral cortex. *Med. Times and Gazette.* 1882, Jan. 28.

9. 1889. MILLS, C. K. Brain specimens chiefly illustrating localization. *University Med. Magazine*, November, 1889. (Philadelphia.)